# Watersheds and Cayuga Lake, 1972-2011

**David Bouldin, Emeritus Professor**

Seminar for Crop and Soil Science August 28, 2014

UNITS

Volume of lake = 10,000 million cubic meters ~ 10,000 million cubic yards

If a tornado sucked all of the water out of the lake it would take 10 to 15 years to refill

Deepest part ~ 400 ft

Concentration of phosphate

A few parts per billion =PPB or

Micrograms per liter ~ 0.000005 grams/liter

Milligrams per cubic meter~ 0.005 grams per M^3

Note nitrate concentrations commonly ppm,

~ 1000 times the concentration of phosphate

**Example**: I cubic meter of 1969 detergent would increase phosphate concentration in lake by about 3 to 5 ppb

Chlorophyll concentration ~ commonly PPB ~ Microgram per liter

PPB chlorophyll ~= PPB phosphate taken up

Carbon content ~ 40 to 100 times chlorophyll content

Biological activity in Cayuga Lake depends on photosynthesis by algae ; algae limited by phosphate and measured by chlorophyll

Chlorophyll and phosphate are measured using standard, universally accepted methods.

All data is on line or in theses at Cornell:

B. J. Peterson.1971

P.J. Godfrey.1977

Available to all.

Summary of Relationships:

Inputs from streams determines phosphate

In deep lake which determines

phosphate in surface water in the spring which

determines algal proliferation in  summer

which is measured by chlorophyll.

**Five years ago I decided to assemble stream and lake data from 1972 – 2011**

**Since 1972 I had collected about 2000 water samples from watersheds**

**About 2000 Lake data available for same period.**

**I had professional interest.**

**I wanted to challenge my brain.**

**In the 1960s environmental quality was major concern at Cornell University. Agriculture realized "Food production, Agriculture and the Environment" required an integrated approach.**

**Started In 1972, late Robert J Young assembled team of professors, post docs, grad students and research staff.**

During 1972 – 1977 produced several theses, scientific publications, book, bulletin.
Major emphasis on lake, stream water, agricultural economics, animal science, manure management, rural sociology.
AND INTEGRATION OF ALL OF THE ABOVE

# NITROGEN AND PHOSPHORUS
## Food Production, Waste and the Environment

Keith S. Porter, Editor
New York State College of Agriculture and Life Sciences
A Statutory College of the State University
Cornell University
Ithaca, New York

A Report of an Interdisciplinary Research Project

Robert J. Young, Director

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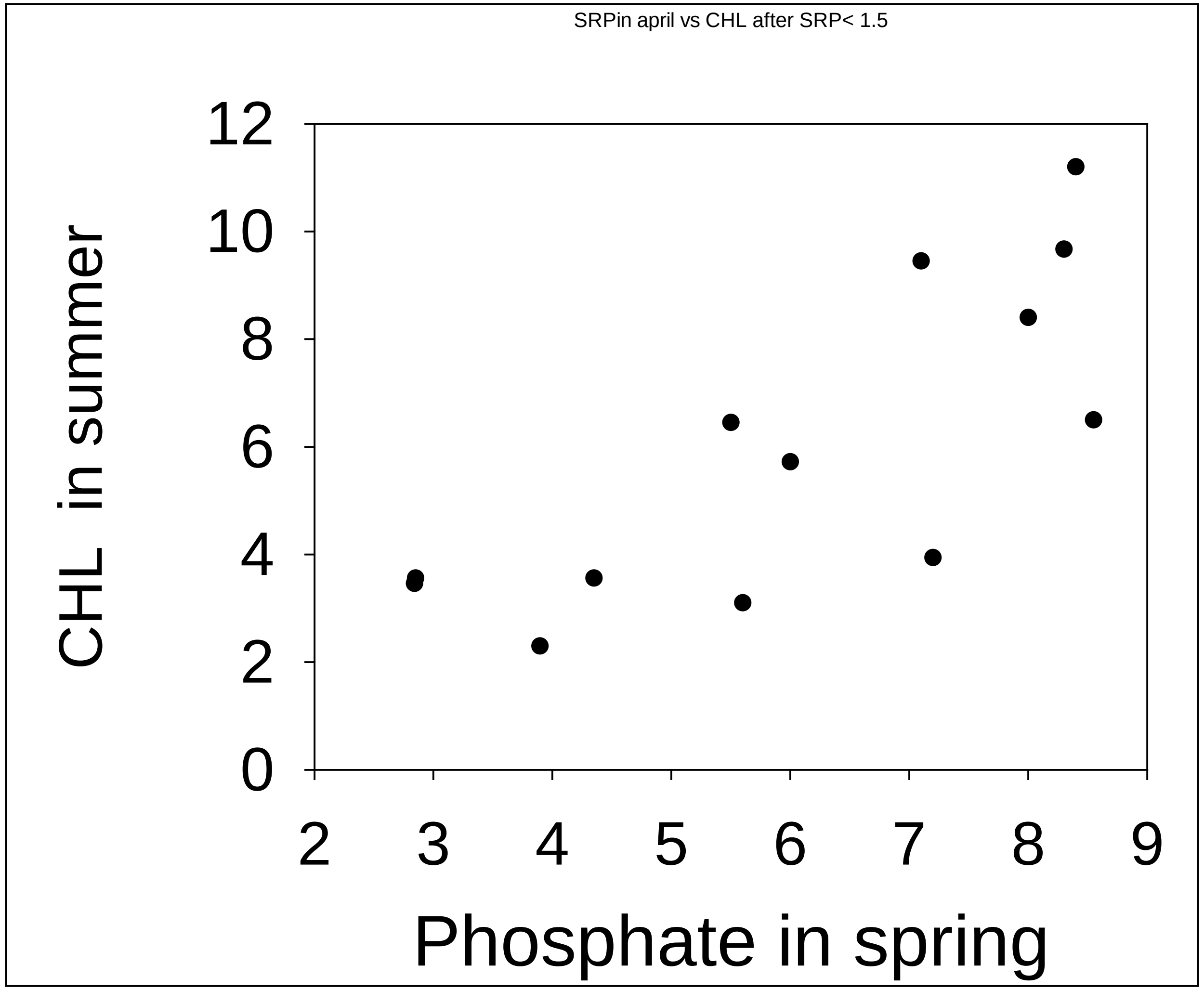
# Project Authors

| | |
|---|---|
| D. R. Bouldin | J. J. Meisinger |
| H. R. Capener | R. T. Oglesby |
| G. L. Casler | K. S. Porter |
| J. J. Jacobs | W. S. Saint |
| A. H. Johnson | W. R. Schaffner |
| D. A. Lauer | E. G. Srinath |
| R. C. Loehr | R. J. Young |

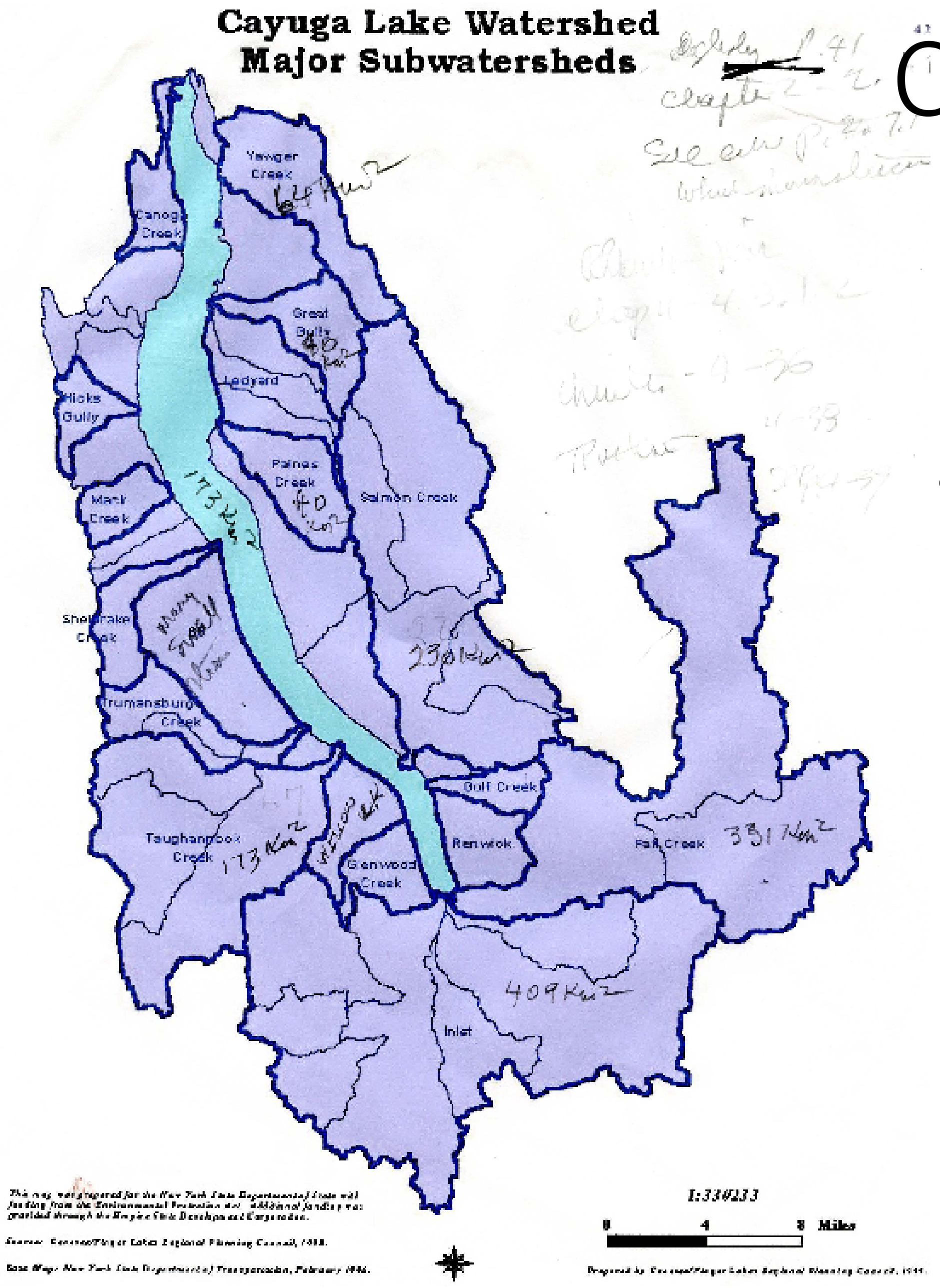
# From 1977 summary

- The levels of algae in the lake are determined by the dissolved phosphate present in the lake in early spring
- Enrichment of algae is reversible by reducing phosphate inputs
- **Is this consistent with the 1999 to 2011 data ???**




This illustrates the relationship between phosphate in spring and Chlorophyll in summer
Now we turn attention to how the SRP in spring is related to phosphate inputs from streams

# Cayuga lake and watershed




Our major interest is in the southern watersheds. About 40% of total area drains into south end of lake.

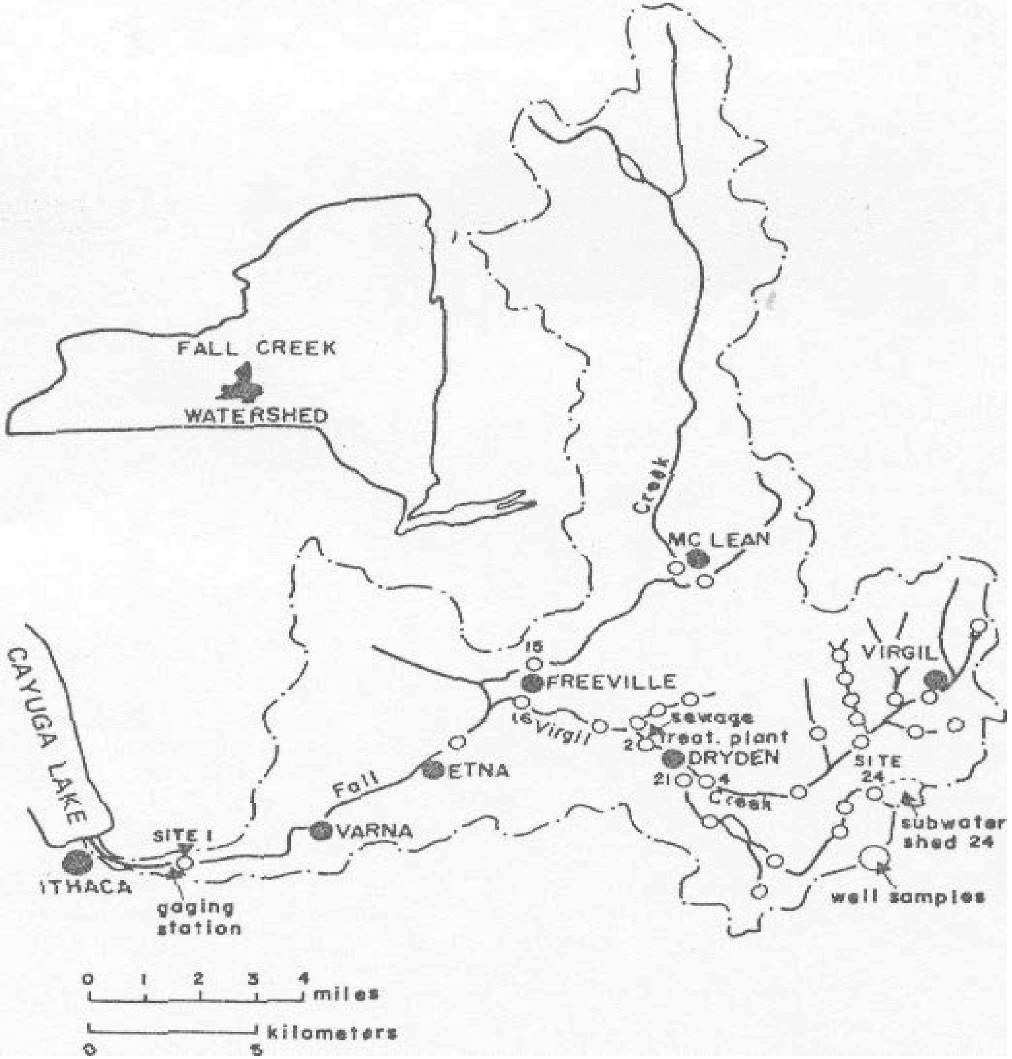
The map on the left defines the source of the drainage entering the lake. The surface area of the lake is about 10% of the watershed area.

Fall creek is our “Model” watershed because:

1. Mix of land uses ~ typical of rest of lake sheds

| | %Agricultural | %Forest |
|---|---|---|
| Fall Creek | 43 | 32 |
| All watersheds | 48 | 31 |

2. USGS Flow data from 1926 through present
3. Sampled 100 feet above USGS station and one block from my home
4. Analysis in my laboratory adjacent to my office
5. 20% of watershed area.



FALL CREEK
WATERSHED
CAYUGA LAKE
ITHACA
SITE 1
gaging station
VARNA
Fall
ETNA
FREEVILLE
15
16 Virgil
Creek
MC LEAN
sewage treat. plant
2
DRYDEN
21
4
Creek
VIRGIL
SITE 24
subwater shed 24
well samples
0 1 2 3 4 miles
0 5 kilometers

Main sampling site:
Pleasant Grove rd and Forest Home Drive


Samples from here


THAW


Storm flow
5 12 '96


Control dam USGS site


west of Dryden


near McLean


Loc 106 looking toward Fall Creek


Fall Creek near Loc 106


Interface between crop land and
riparian denitrification/ immobilization zone (???)


Lake Como and beginning of  Fall Creek


Fall Creek below Lake Como

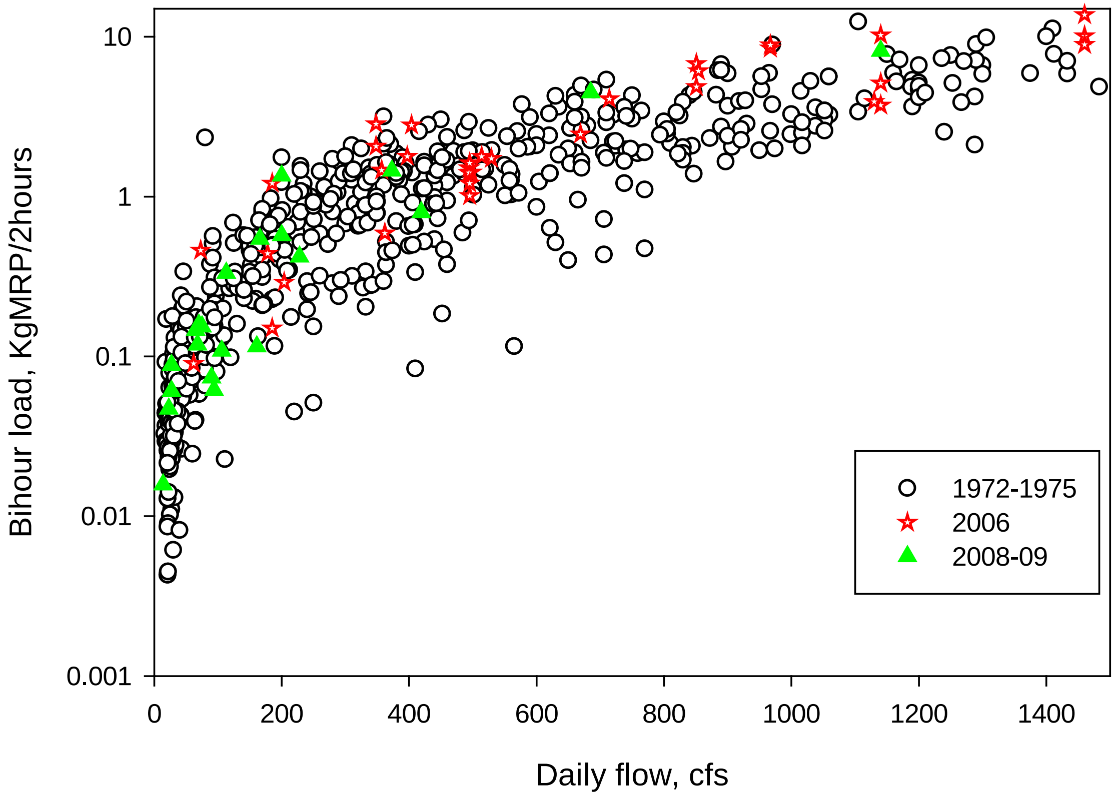

Virgil Creek


How much NO3?

Newfigs82014
mrp09v21110-13

# Logarithm of load vs flow

Load = concentration*flow




FLOW

Load vs flow, 1972- 2008

Note the different color symbols:

Black, 1972- 1975

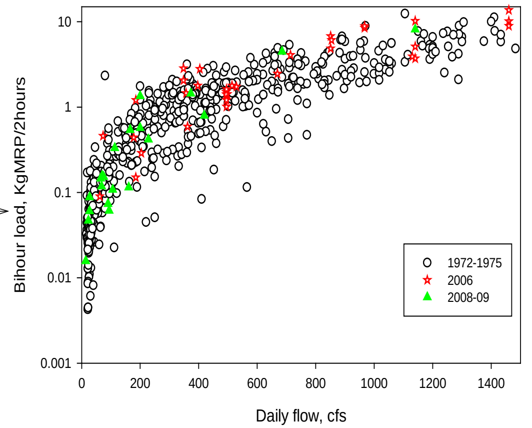
Red, 2006

Green, 2008-2009

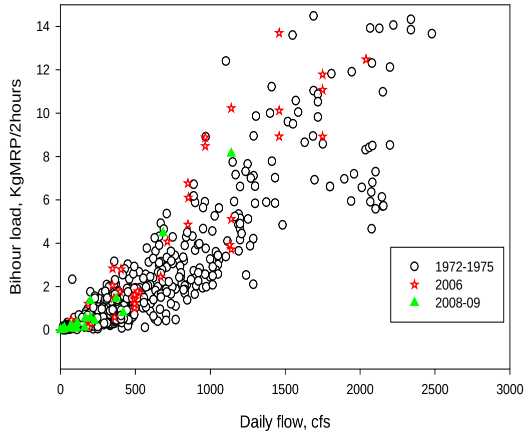
**Conclusion** no change in load vs flow, 1972-2009

Load=concentration*flow

LOG




LINEAR




# Tricks of dealing with variability

1. Load vs flow
2. Log or linear –

units of factors of 10: 0.1, 1, 10

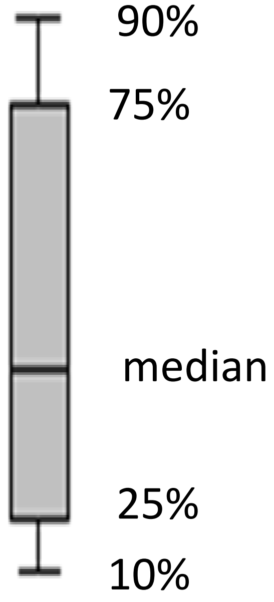
OR

units 0, 2, 4, 6, 8, 10

3. Take lots of samples
4. Sample all seasons, years
5. Sample storms, low flow

# Flow Alternate to load: Concentration vs range of cfs

Box plot:

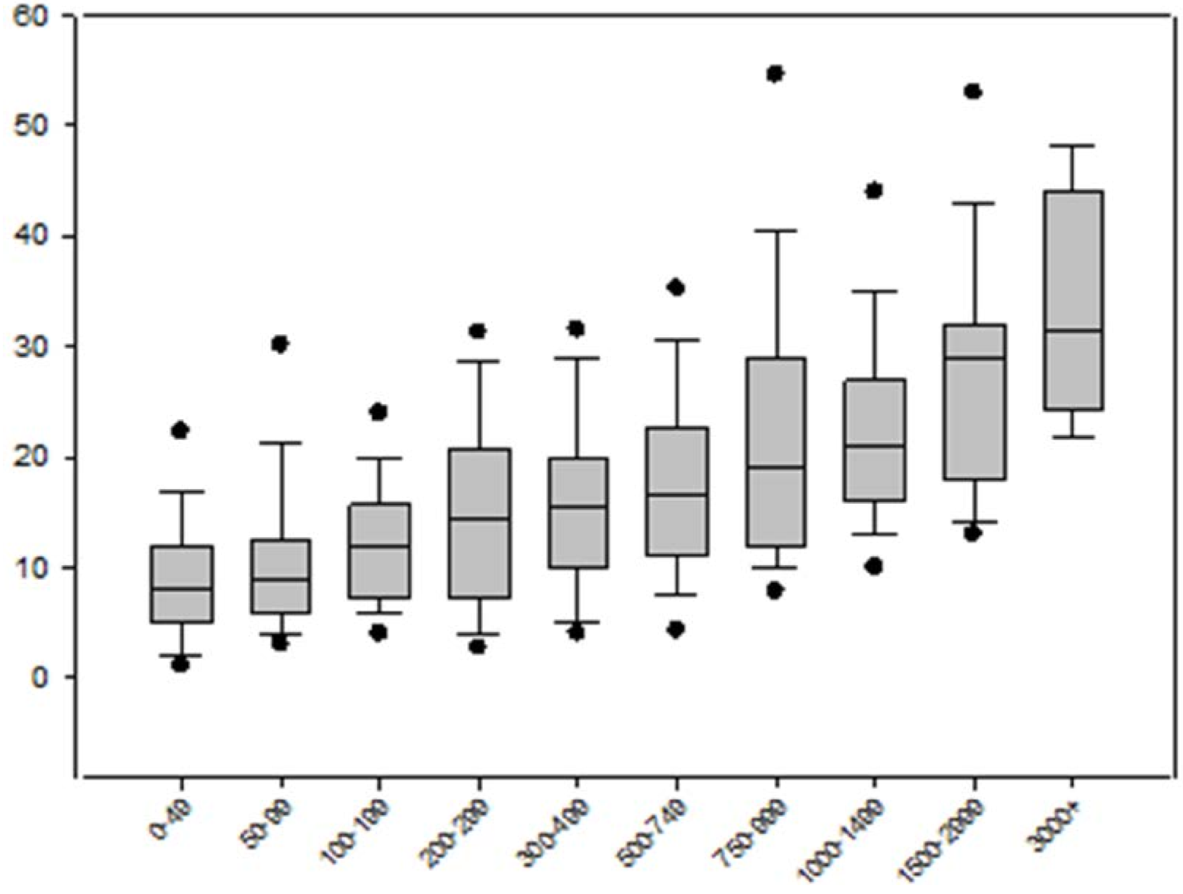



Illustrates range of variability

750 samples

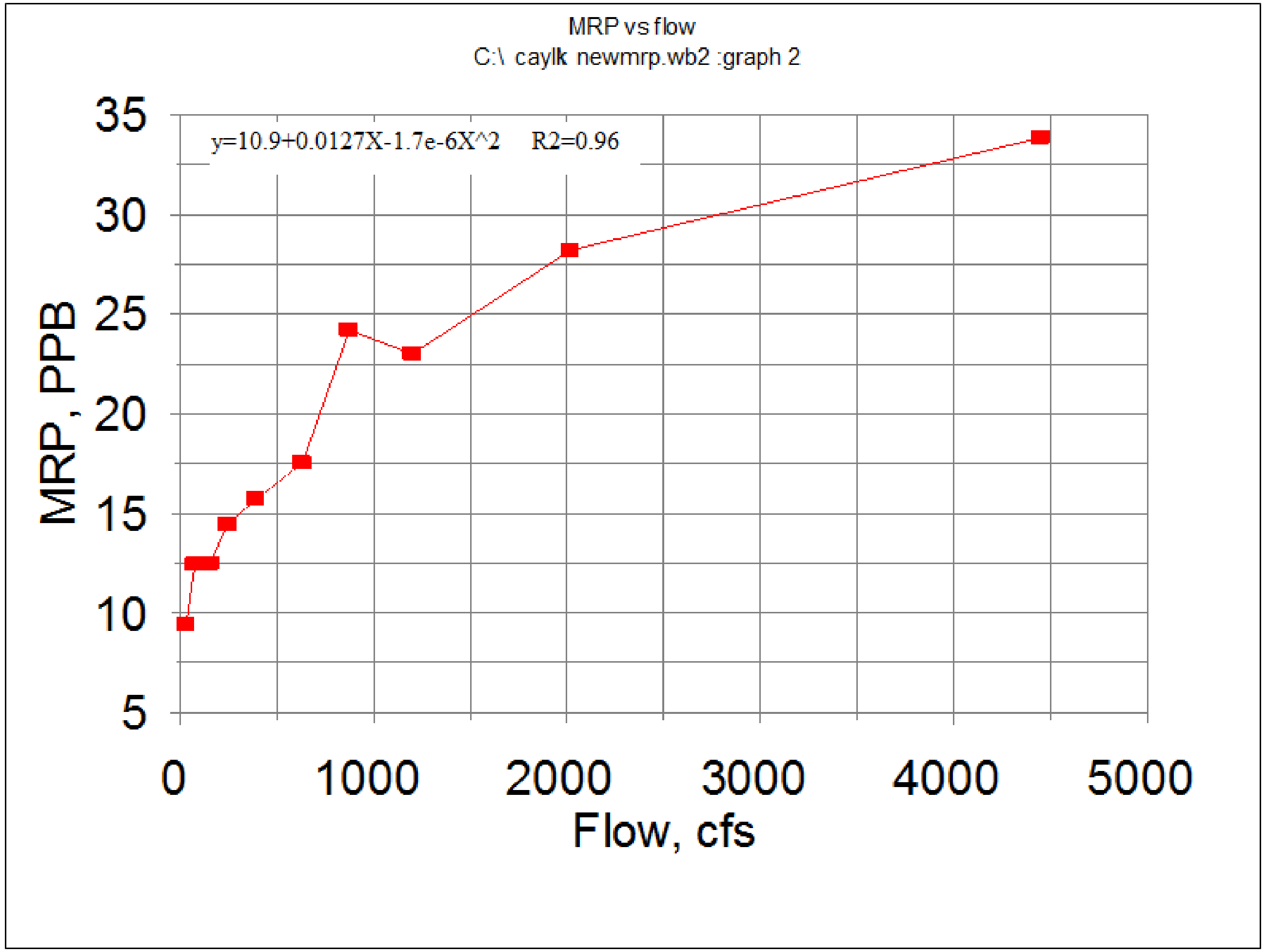
Phosphate

average MRP on average flow
10.89+0.0127*cfs-1.7e-6*cfs^2




Flow Range, CFS, 0-49, 50-99,……1500-2000

| | |
|---|---|
| C:\caylk\mrpxflowxls.xls | |
| average MRP on average flow | |
| 10.89+0.0127*cfs-1.7e-6*cfs^2 | r^2=0.96 |



Now we have defined load and concentration for Fall Creek, 1972 to 2008.
Next we need to extrapolate to all of watersheds.
First approximation: flow per unit of drainage area is same for all watersheds; since area of Fall Creek is 20 %, 5 times Fall Creek flow = flow for whole watershed
This is based on data and rational expectations.

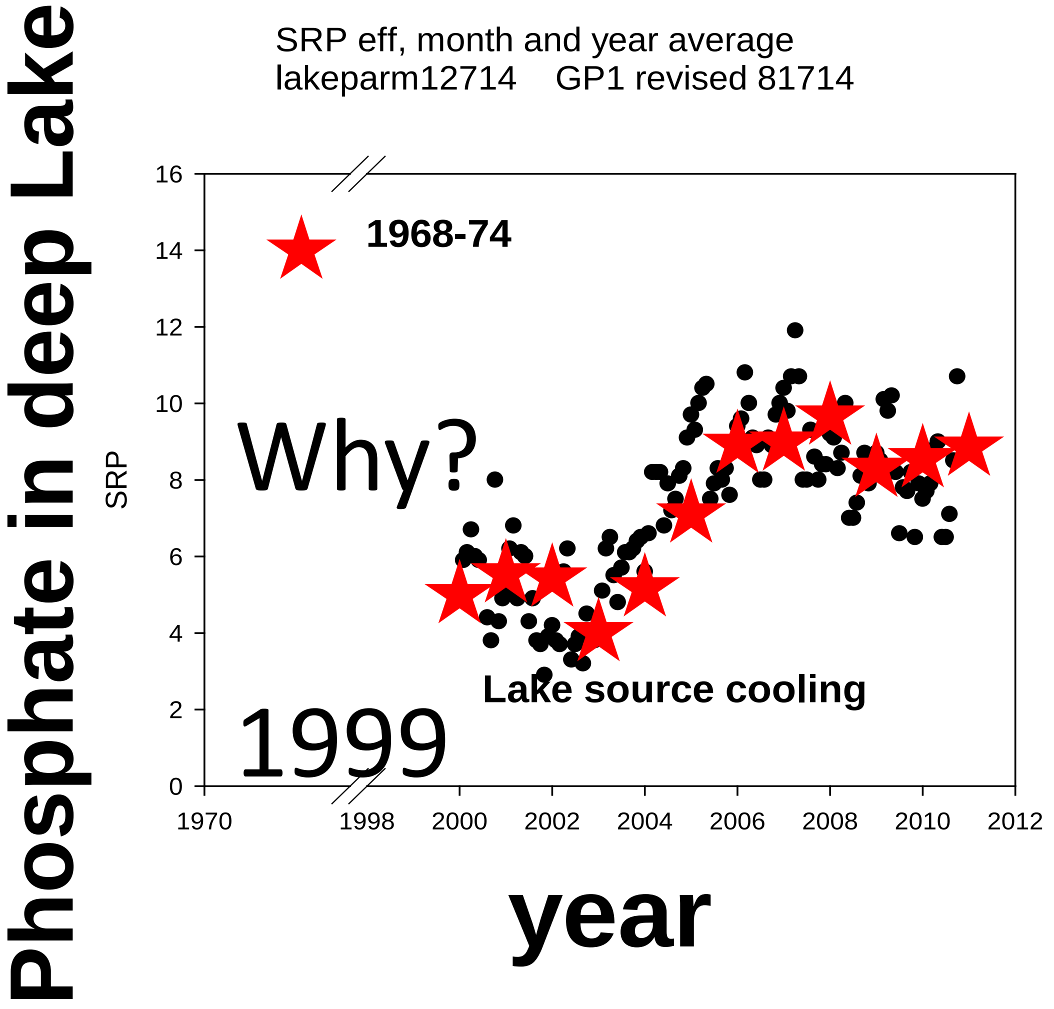
No doubt as you expect the next approximation**: the product of flow times concentration relationship for Fall Creek is applied to all of the watersheds**.
OR **load for whole watershed is 5 times Fall Creek**

So Far we have developed loading from watersheds

**Now we turn attention to how to relate this to phosphate in the lake and  algal production as measured by chlorophyll.**

**Universally accepted: During fall and winter lake cools and whole lake reaches point of maximum density at 4 C or 37 F. By late march the dissolved constituents in the lake are equal: north to south, east to west, top to bottom. During summer the surface warms up and the warm water floats on top of the cold; with warming algal growth begins in the surface layer.**

**The above leads to the following conclusions: the phosphate concentration in the deep, cold water in the lake is an integrated average of the stream inputs over months and years Recall lake deeper than 60 meters does not mix during summer with warm surface Deep water (greater than 60 m) phosphate changes slowly over years**




Why the large difference between 1974 and 1999 ?

**Difference** = -8 in 1999 and -6 in 2010 change in phosphate in domestic sewage kg/cap/yr.

In 1972 0.9 kg excreted+0.6 kg from detergent=1.5 kg/cap

By 2005 100 % of detergent P and 50% 0f excreted P :

= - 1.1 kg P cap/per year

for 40000 sewered change= - 44000 kg P/year

For 40000 unsewwered = - 11000 kg p/year

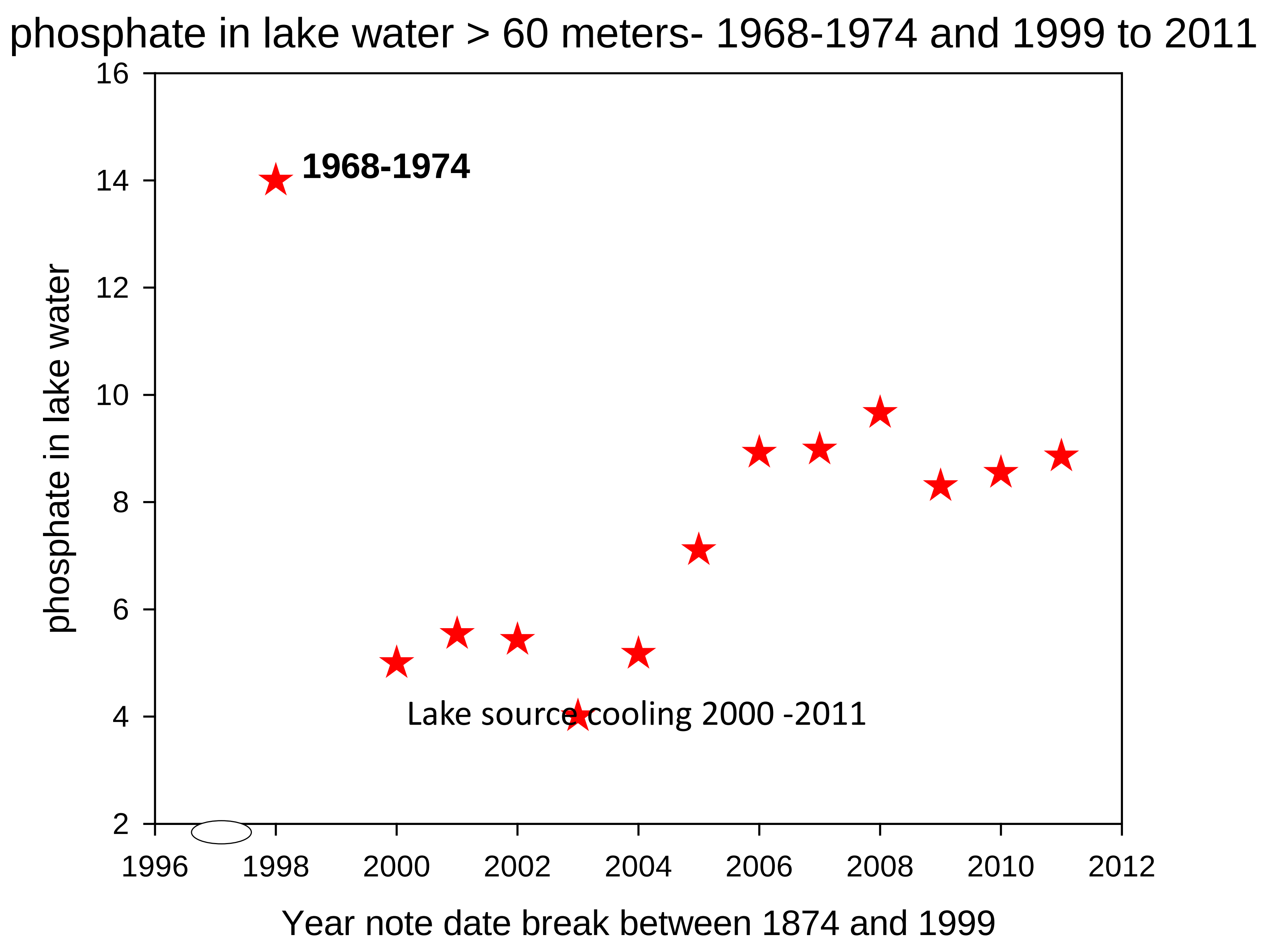
Net - 55000 kgP/per year

10,000 million m3 of lake water;change =- 5.5 ppb

0r 14 ppb in 1974 to 8 ppb in 2010 = - 6 ppb

**Domestic sewage explains difference**

jan14\lakeparmgp17



# Lake vs streams

Lake is very large: annual inputs from all the watersheds varies between 10 and 15% of the lake volume or 10 to 15 years will be required to completely replace lake water

# Prior to 1972 chloride increased from added mined salt but not added after 1972:illustrates slow change to lower concentration over years

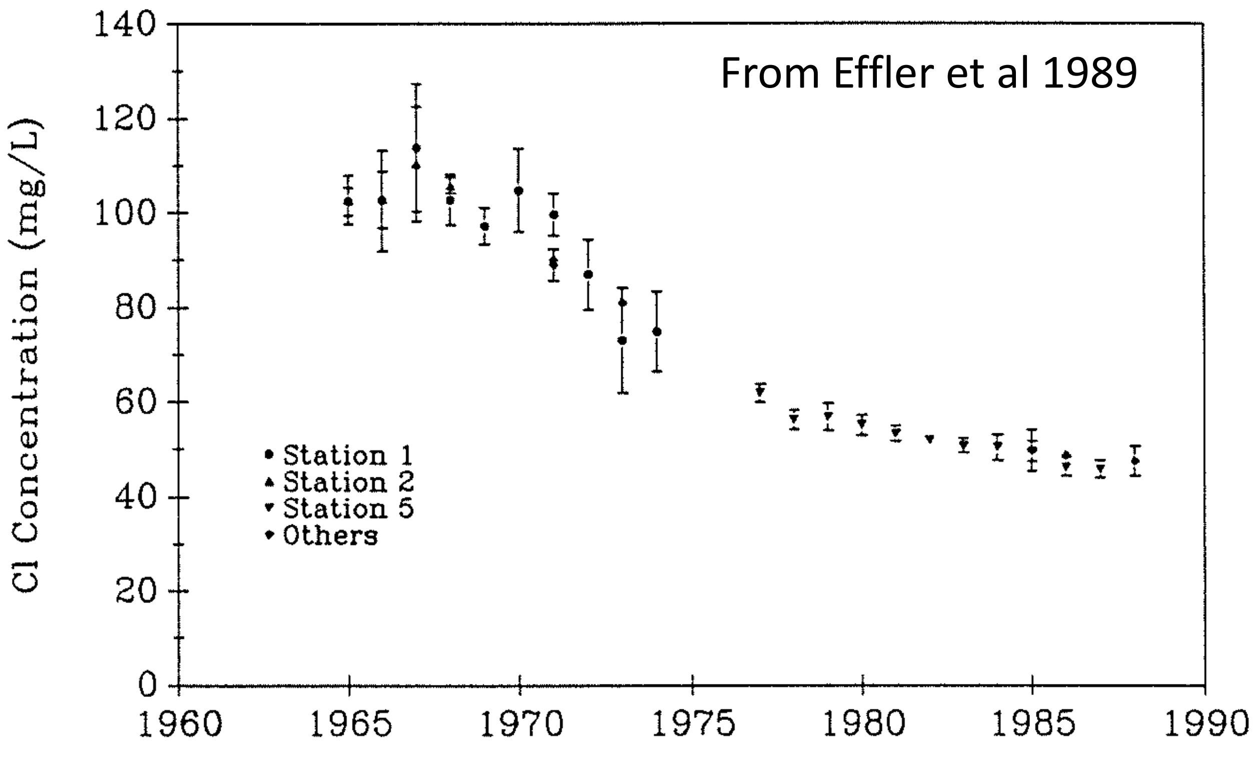
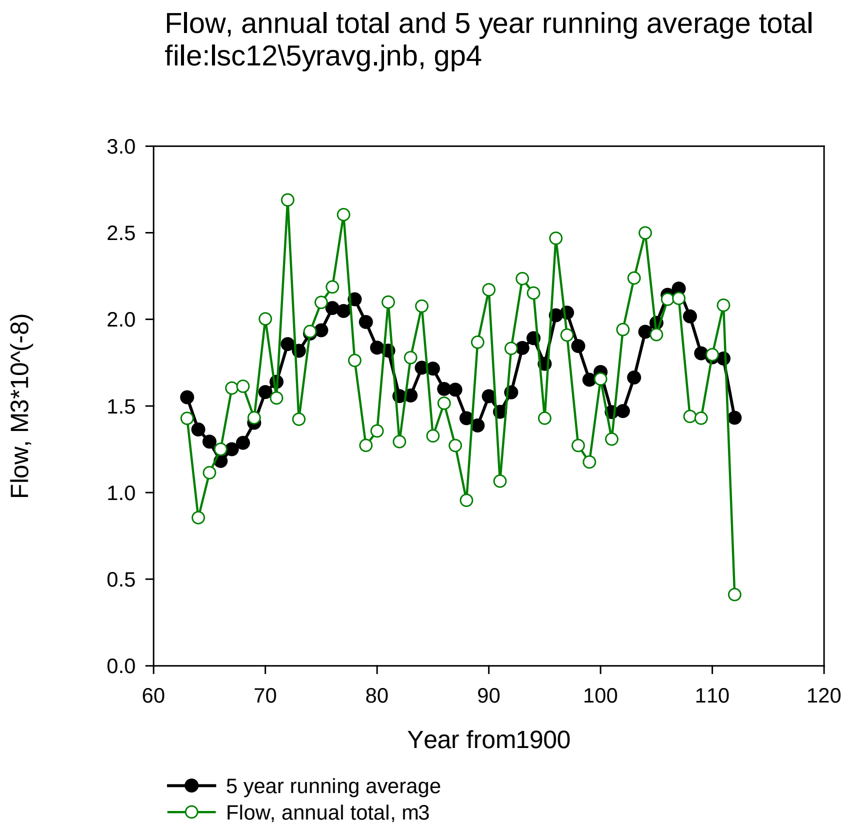



Fig. 3. Annual average Cl concentrations in Cayuga Lake, at various positions, from 1965 throug 1988. Vertical bars (± one standard deviation) represent variability measured in each year.

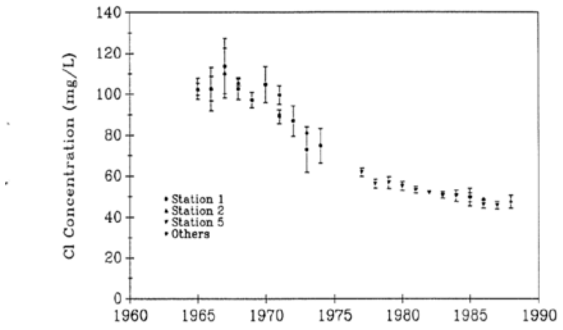
~ 100 ppm in 1970 to ~60ppm in 1976




Year 1962 to 2010

Basically the yearly flow is on the order of 10 to 15 % of the lake volume – The graph on the left is flow per year and an example of 5 year average flow.

Amount of flow determines amount delivered to lake!!!

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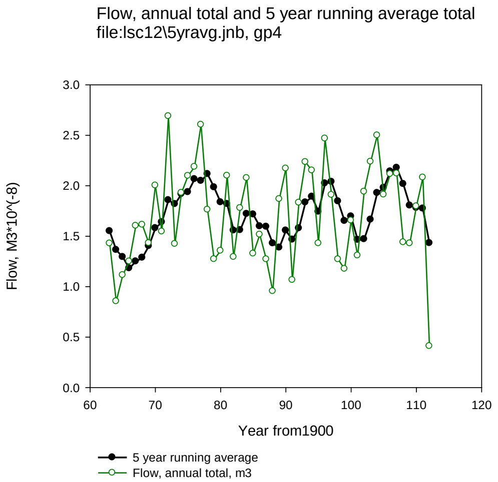
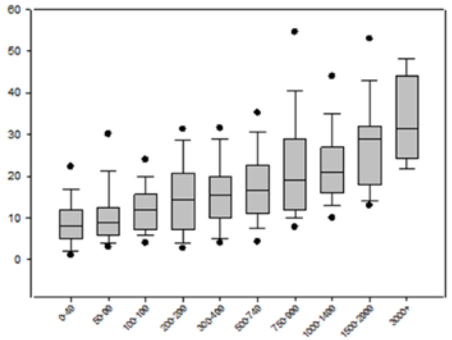
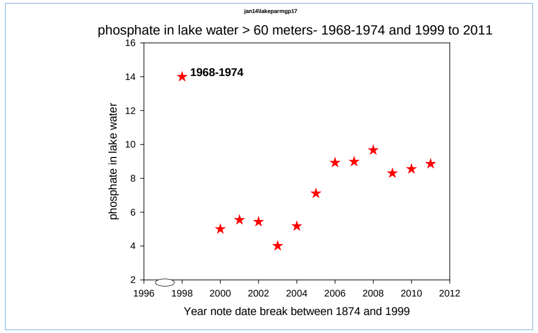





Chloride data shows lake responds to streams over years, Flow graph shows yearly and episodic stream flow, box graph shows concentration in stream inputs, right graph shows lake concentration. So how many years of stream load will yield concentration in lake???

Created spread sheet, listed USGS flow for each day, calculated load into lake for each day, then amount delivered to lake during preceding year, preceding 2 years, preceding 3 years etc
Next created correlation matrix; First column lists concentration in deep lake for each year, next column lists load for year, next preceding 2 years etc. through 10 years

# Example matrix

| | | | | |
|---|---|---|---|---|
| | | …….stream P……… | | |
| year | lake P | 1yravgsrp | 2yravgsrp | …….. |
| 2000 | 5.00 | 1.92 | 1.97 | …….. |
| 2001 | 5.54 | 2.64 | 2.28 | …….. |
| 2002 | 5.43 | 2.14 | 2.39 | …….. |
| 2003 | 4.01 | 3.21 | 2.67 | …….. |
| 2004 | 4.20 | 3.80 | 3.50 | …….. |
| 2005 | 7.11 | 4.23 | 4.02 | …….. |
| …… | …… | …… | ….. | ETC |

correlation **coefficients lake phosphate** and stream phosphate

| | Phosphate | | | | DAYS IN AVG |
|---|---|---|---|---|---|
| 1yavg | 0.14 | | | | 365 |
| 2yravg | 0.40 | | | | 730 |
| 3yravg | 0.57 | | | | 1095 |
| 4yravg | 0.72 | | | | 1460 |
| 5yravg | 0.84 | | | | 1825 |
| 6yravg | 0.89 | | | | 2190 |
| 7yravg | 0.73 | | | | 2555 |
| 8yravg | 0.58 | | | | 2920 |
| 9yrAVG | 0.59 | | | | 3285 |

Coefficient = zero if no relation ship, = 1 if perfect relationship the **link between streams and lake**

CONCLUSION: **Stream inputs averaged over previous 6 years is best estimate of concentration of deep water in lake** correlation coefficients between selected varaibles, 2000 to 2011

| | 6yr | eff | lkapr | allchl |
|---|---|---|---|---|
| **6yr** | | | | |
| **eff** | **0.93** | | | |
| **lkapr** | **0.62** | **0.77** | | |
| **allchl** | **0.71** | **0.79** | **0.65** | |

*correlation coefficient 1% probability level =0.68*

*6yr = 6year sum stream*

eff= phosphate in lake source cooling

lkapr= phophate in surface lake in early april

allchl=average chlorophyll in summer

Summary of Relationships:

Inputs from streams determines phosphate

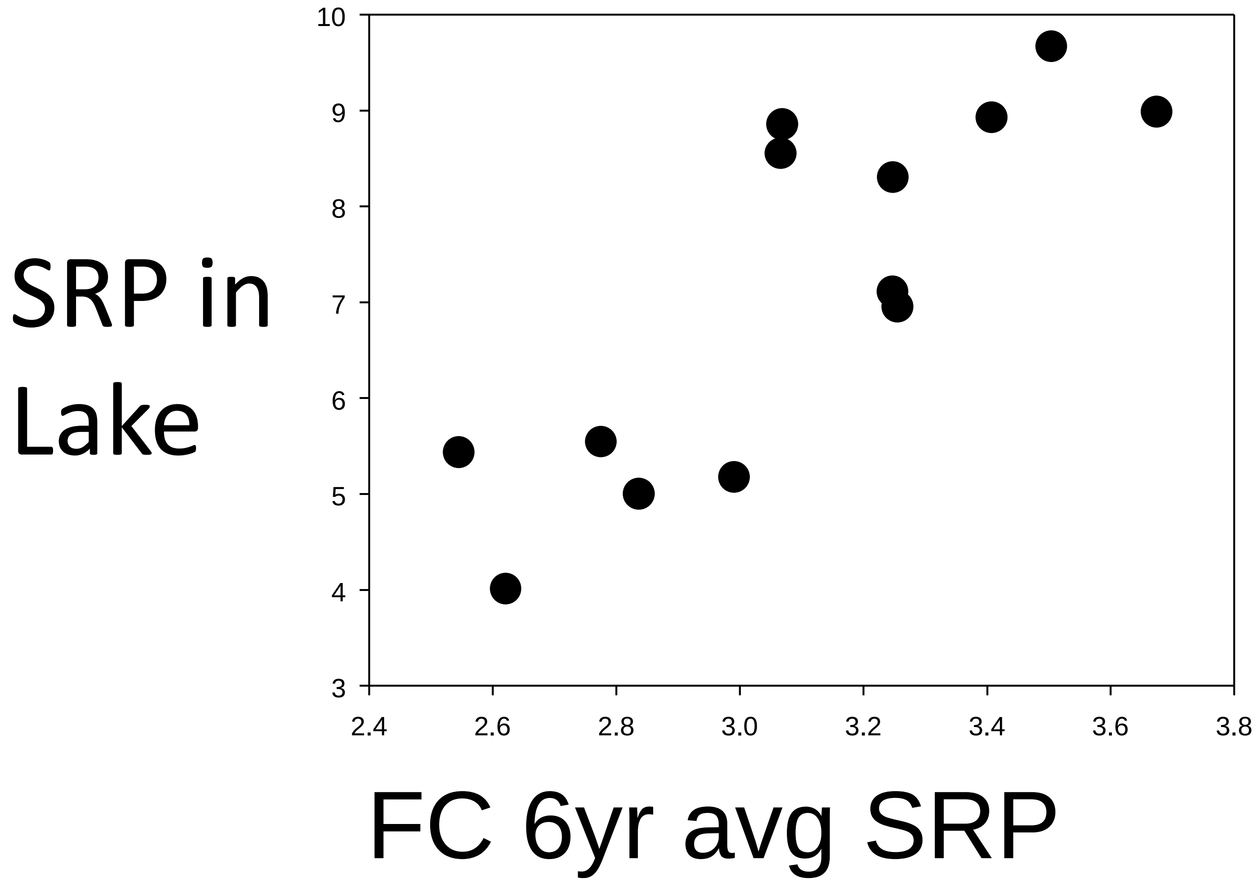
In deep lake which determines

phosphate in surface water in the spring which

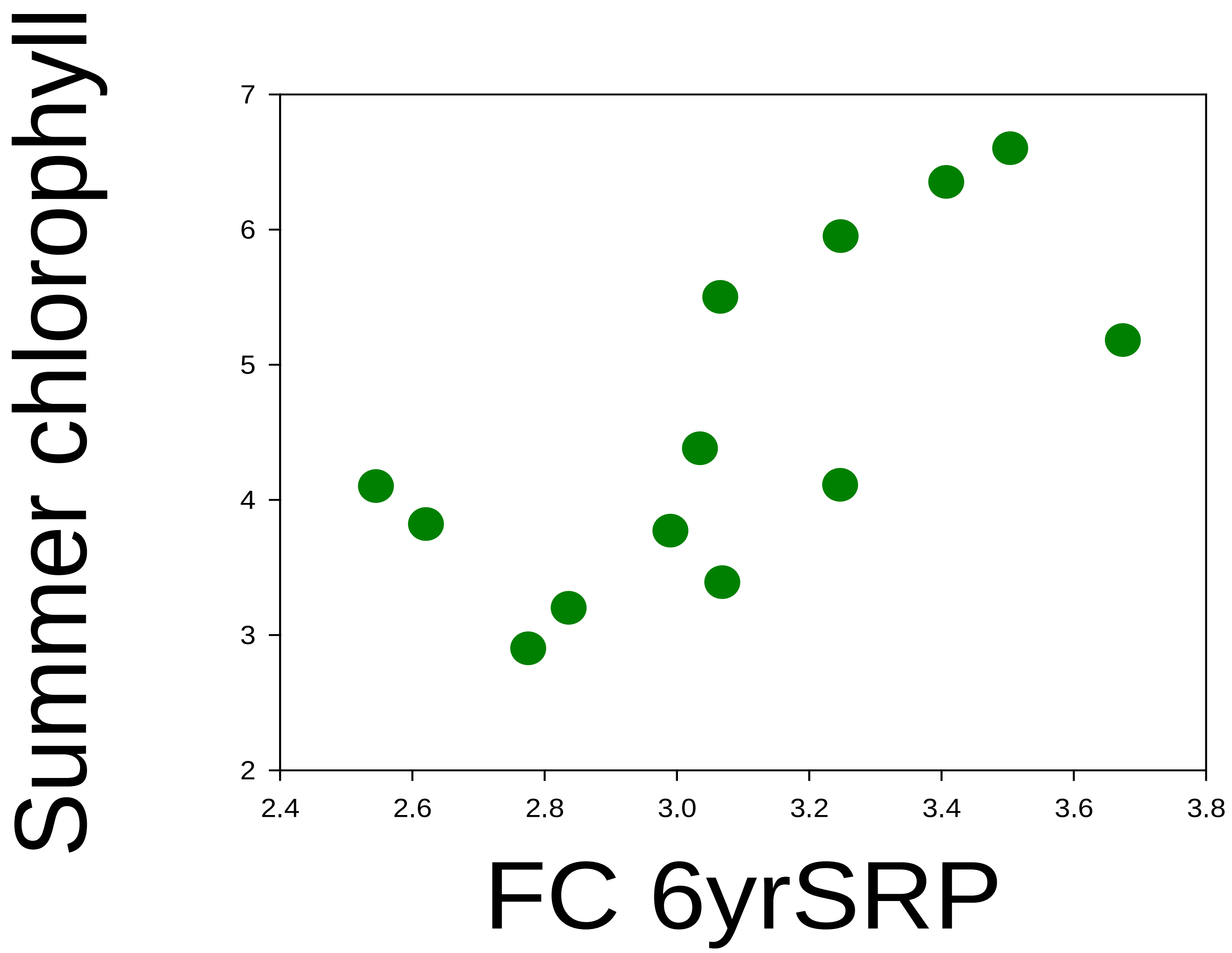
determines algal proliferation in summer

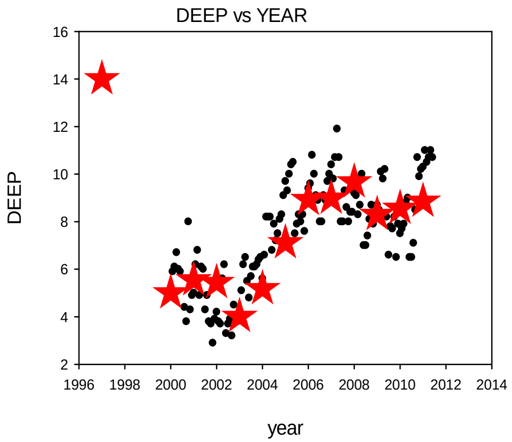
which is measured by chlorophyll.

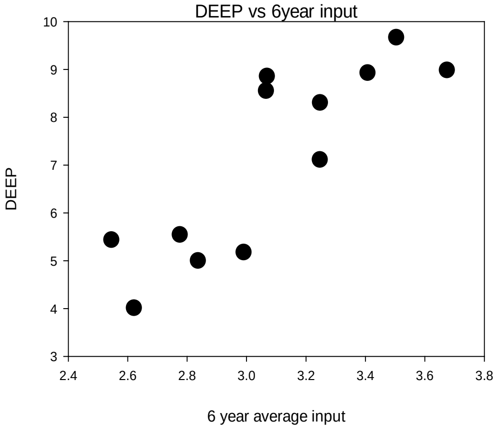
# Summary of 40years

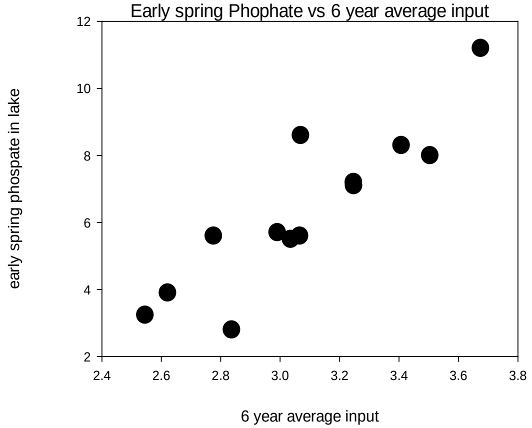


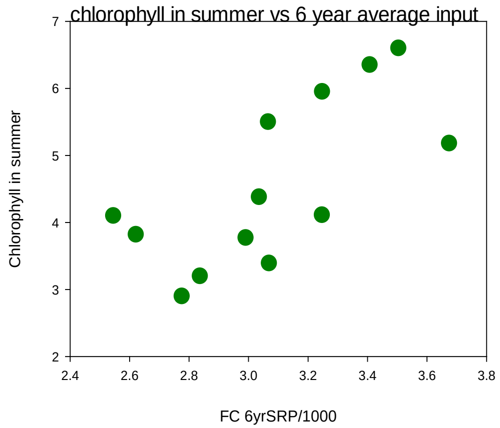
# Summary of 40 years






Summary slide: concentration in DEEP water in lake vs years and vs **6yr average inputs of streams, early spring phosphate** surface of lake and **chlorophyll in summer** vs 6yr inputs of phosphate from streams.

General summary, Lake

1. Phosphate concentration varied from 4 to 15 microg per liter,  1974- 2011.
2. Concentration of phosphate in spring is correlated with 6 year average of phosphate input from streams.

1. Chlorophyll increased and decreased in phase with this variation but there is variation not explained by phosphate: this is multivariable problem.
2. Chlorophyll concentration has varied from 4 to 10 micro grams per liter with in the period 1968 to 2011. This is guide to future

**The phosphate dissolved in the water has no important influence on the “macrophytes” , “so called weeds” etc which are usually restricted to the shallow (less than 6 to 8 meters of water depth);** presumably they receive their phosphate and some other nutrients from the bottom sediment.

Actually, I suspect that no one of us would be able to discern the difference between chlorophyll associated with 15 and 4 units of phosphate unless we analyzed multiple samples with a spectrometer.

a. As you no doubt have observed, the clarity of the lake varies widely; most is consequence of **suspended solids plus chlorophyll; suspended solids remnant from sediment.**
b. in early spring chlorophyll is almost zero and during summer concentration varies widely

1. The easiest way to predict future chlorophyll/ algal concentrations in summer is phosphate in lake source cooling water, which I presume will continue to be measured by Cornell.
2. Also John Hafman, Hobart William Smith, has collected and published several years of data in far more detail than lake source cooling so if he continues his work then we need not duplicate his work.

1. Currently consultants and DEC are / will develop lake and watershed models; by 2017 there will a TMDL (TOTAL MAXIMUM DAILY LOAD) model?
2. **I am of the opinion that currently the quality of the lake is very good to excellent.**
3. **But the great challenge is invasive species – do we know how to manage them????**

# Last slide